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PRODUCTION OF DOMESTIC HOT WATER WITH SOLAR THERMAL COLLECTORS IN NORTH-EUROPEAN APARTMENT BUILDINGS

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ABSTRACT

The production of domestic hot water with solar thermal collectors in apartment buildings has been studied. The annual energy output of the solar collector was calculated with the PolySun simulation program using the Meteotest Estonian climate file. Weather data were measured in a solar radiation measurement station situated at Tallinn University of Technology. The results of the measurements of the solar thermal energy system of the tested apartment building have been presented. The results of the analysis confirm that solar thermal collectors are one of the best possibilities of reducing the consumption of conventional energy resources in apartment buildings.

Key words: Solar thermal collectors, domestic hot water, Polysun simulations, apartment buildings, North-European countries

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1. INTRODUCTION

According to European Union Directive 2010/31/EC on the energy performance of buildings, all new buildings including apartment buildings need to meet the requirements of nearly zero-energy buildings starting from 31 December 2020 (public buildings after 31 December 2018 and all other buildings after 31 December 2020). Therefore more alternative energy resources have to be used. According to previous studies, solar thermal collectors show potential to satisfy the consumption of domestic hot water production [1-5]. It is reasonable to use solar thermal energy for producing DHW because the daily consumption is quite constant throughout the year, but in

comparison, the heating demand varies a lot. At the same time, the consumption of DHW in different buildings can vary considerably. It depends on people's habits, the time of the year, and the inhabitants' lifestyle. [6]. During the last two decades DHW consumption in Estonian apartment buildings has decreased [7]. The present study focuses on the usage of solar thermal collectors in North-European (Estonian) apartment buildings for producing DHW and describes one case study.

2. METHODOLOGY

2.1. Theoretical background

There are basically two types of solar collectors: non-concentrating or stationary and concentrating. A non-concentrating collector has the same area for intercepting and absorbing solar radiation, whereas a sun-tracking concentrating solar collector usually has concave reflecting surfaces to intercept and focus the sun's beam radiation to a smaller receiving area, thereby increasing the radiation flux. [8]

The most common type of solar collectors is stationary collectors. The main types of stationary collectors are:

1. Flat plate collectors; [12]
2. Stationary compound parabolic collectors;
3. Evacuated tube collectors.

Estonian solar energy market uses only flat plate collectors and evacuated tube collectors.

Solar irradiation depends on the geographic location, mainly on the latitude, the slope of the collector and direction. Solar irradiation also varies considerably from year to year causing a large variation in the solar collector delivered heat. The span around the average value for a 16-year period is around 20% for the flat plate and 15% for the vacuum tube collector for an operating temperature of 50°C [9]. It must be noticed that in low solar irradiation regions solar radiation intensity must exceed 300 W/m2 in order to heat the collector so that it can deliver energy.

In Estonia solar thermal energy is mainly used for producing domestic hot water and in spring and autumn for space heating. [13] In winter Estonian solar resource is limited and the production of the solar thermal system is minimal.

Table 1 Main characteristics of the building

Pos	Parameter	Data	Unit
1	Stories	4	pc
2	Number of apartments	11	pc
3	Building footprint	280	m^2
4	Useful area	836.5	m^2
5	Volume of the building	2980	m^3
6	Enclosed gross area	1020.7	m^2
7	Closed net area	836.5	m^2
8	Residential area	721.2	m^2

2.2. The studied building

The test building is situated in Tallinn. It was built in 2007 and was one of the first buildings in Estonia, which installed a solar thermal collector to produce domestic hot water. The main characteristics of the building are presented in Table 1. Near the test

building there is a group of buildings, which were built according to the same construction project. In these buildings solar thermal collectors have not been installed.

Figure 1 Solar thermal collectors on the roof of the test building

Table 2 Characteristics of EURO C20 AR collector

Parameter	Data (per one collector)
Collector area	Total area 2.6 m^2/aperture area 2.39m^2
Dimensions	2151x1215x110mm (LxWxH)
Casing	Aluminum featuring 60mm side and back insulation without gaps
Glass cover	4-mm solar safety glass with sunarc anti-reflex coating, $\tau = 96\%$
Absorber	All copper absorber panel with highly selective vacuum coating $\alpha = 95\%$, $\varepsilon = 5\%$
Efficiency	$\eta_0 = 0.85$, $k_1 = 3.37$ W/(m^2K), $k_2 = 0.01$ W/(m^2K),
Idle temperature	232 °C
Annual Yield of collector	546 kWh/m2a (ITW 5 m^2)

2.3. The investigated solar thermal system

Six solar thermal collectors have been installed on the roof of the building (Figure 1). Collectors are oriented directly to the south and the tilt angle is 45 °C. There are solar thermal collectors EURO C20 AR from the company "Wagner & CO Solartechnik GmbH". More detailed characteristics of the studied collectors are presented in Table 2. Collectors are divided into 2 groups, which are connected in parallel. Inside the connection groups the collectors are connected in series (Figure 4). The solar energy system includes 2 hot water accumulation tanks, which have been installed in the technical room. The volume of both tanks is 1000 l. The solar heating element is positioned in the lower part of the first tank. After the first tank is heated up, natural circulation helps to heat the second tank. The second tank is connected to the gas

boiler to heat up domestic hot water at the level of +55 °C. The heat transfer fluid in the roof circle is 35 % ethylene glycol and water mixture to ensure frost resistance in the winter time. When the solar collectors are producing too little energy, the gas boiler ensures that the temperature in tank 2 does not fall. The principle scheme of the solar thermal collectors and the connection with the systems is presented in Figure 2.

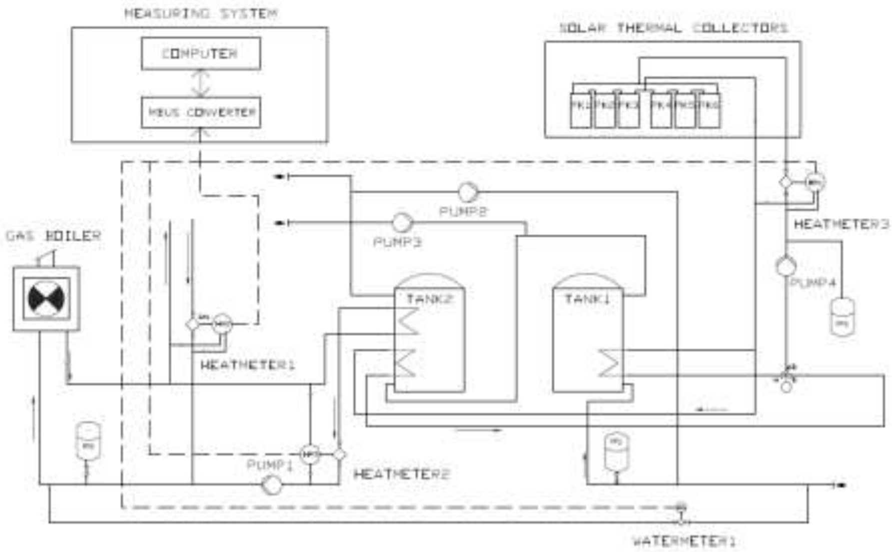

Figure 2 The principle scheme of the heating system and measuring system of the building

3. RESULTS AND DISCUSSION

3.1. The simulations

Yearly simulations were performed by the Polysun 5.5 simulation program. The Polysun program provides dynamic annual simulations of solar thermal systems and helps to optimize them. It operates with dynamic time steps from 1 s to 1 h. [10] The Polysun simulation program is validated by Gantner [11] and was found to be accurate to within 5–10%.

The model of the hydraulic system of the studied system was made as similar as possible to the real situation. The scheme is presented in Figure 3. The main characteristics of the simulated system are presented in Table 3. The total annual energy produced by the solar thermal collectors is 3889kWh. At the same time the collector field yield relating to the gross area is 247kWh/m² and the collector field yield relating to the aperture area is 271kWh/m².

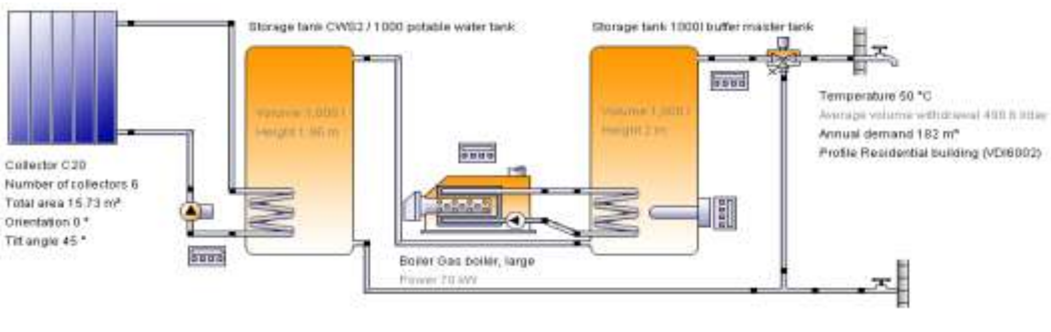

Figure 3 The hydraulic scheme of the heating system (PolySun)

Table 3 Overview of solar thermal energy (annual values)

Characteristic	Data
Collector area	16 m²
Solar fraction total	32.3%
Total annual field yield	3889 kWh
Collector field yield relating to gross area	247 kWh/m²/Year
Collector field yield relating to aperture area	271 kWh/m²/Year

The annual solar thermal energy to the DHW system by month is presented in Figure 4. It is important to notice that in the winter period the production of solar collectors is about 20 times lower that in the summer period. At the same time, from March to September the production is not significantly lower than the maximum monthly production.

The consumption of DHW can be variable in different buildings and it depends on several factors [6]. The DHW system and solar thermal collector are usually designed according to valid local standards. In the case of the test building and the similar neighboring buildings the DHW system has been designed exactly the same way. The only difference is that in the test building DHW is also produced by solar collectors. As the yearly consumption in different buildings varies widely, it is possible to show how the consumption of DHW and the production of solar thermal energy are related. The yearly simulations have been done in 5 different cases. The studied annual DHW consumptions are 73 m3, 182 m3, 322 m3, 360 m3 and 402 m3. The simulation results are presented in Figure 4 and Figure 5. It can be said that in case of a greater consumption of DHW the yearly production of solar collectors can be about 30 % higher. In Figure 4 it is possible to see that the main increase in DHW production occurs in the summer period. At the same time if the consumption of DHW is low, the yearly production of solar thermal collectors is higher compared to the total production (Figure 5).

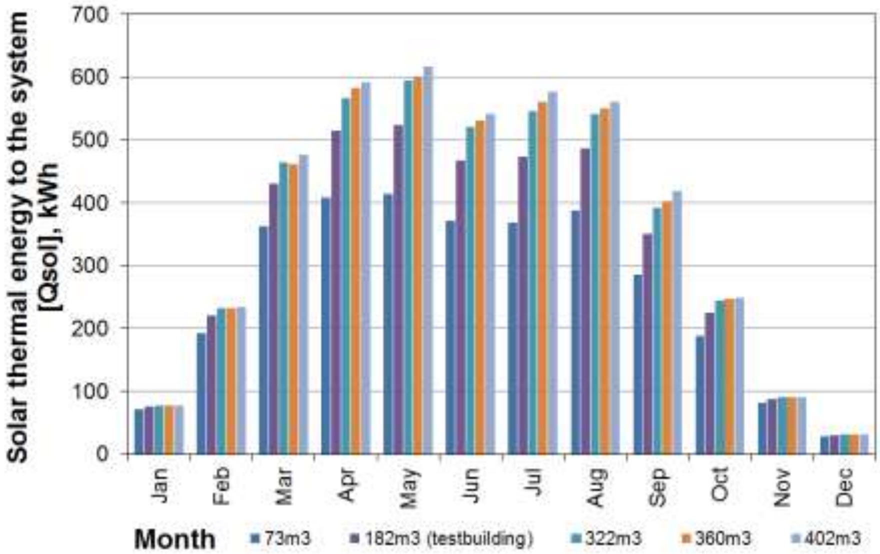

Figure 4 Solar thermal energy to the domestic hot water system in different buildings (simulation)

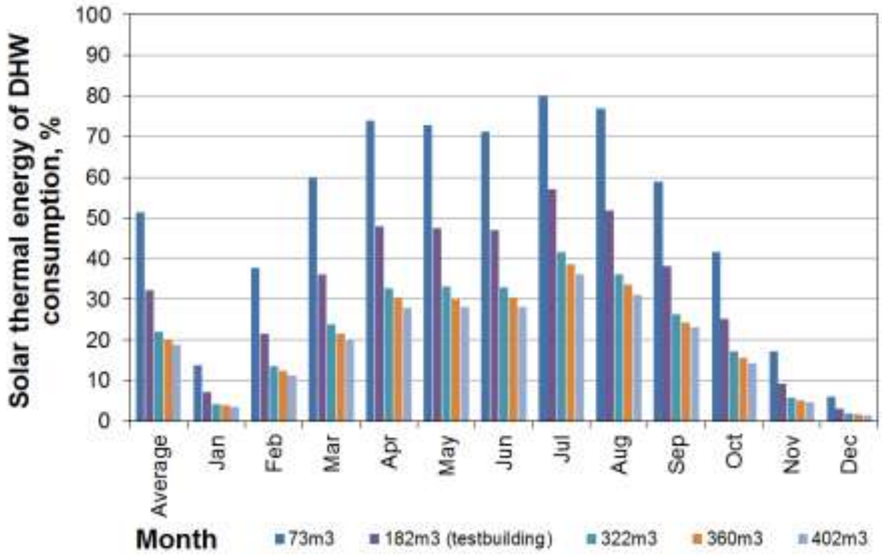

Figure 5 Solar thermal energy of DHW consumption in different buildings (simulation)

3.2 The measured data

The global and diffuse irradiance at the horizontal surface were recorded every hour. The results of the measurements were compared to the data of the Estonian test reference year. In 2010 the measured global and diffuse irradiance were both higher than the values in the simulation.

The comparison of global and diffuse irradiance at the horizontal surface and in Meteotest is presented in Figure 6.

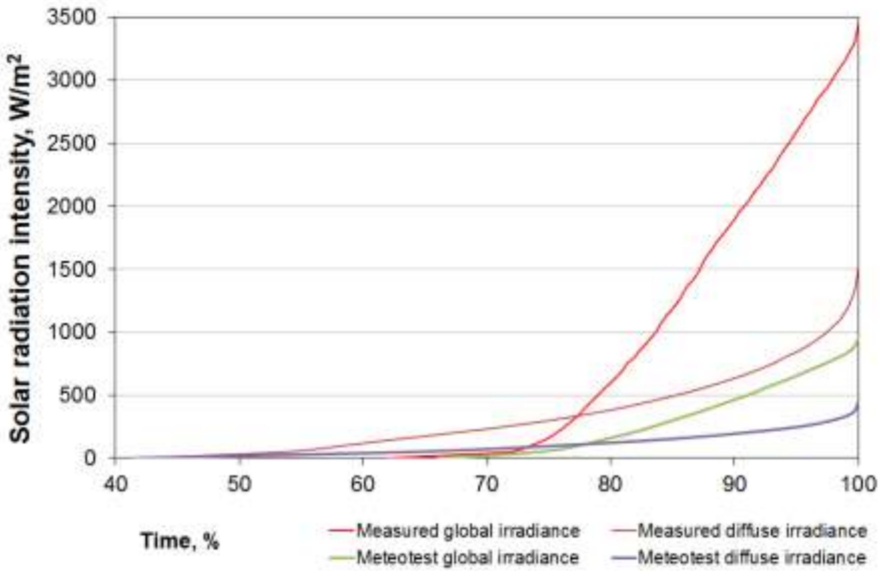

Figure 6 Global and diffuse irradiance at the horizontal surface in the year 2010 and in Meteotest

The production and consumption of heat energy and demand for water are measured with heat and water meters, which have Mbus output. Heat meter 1 and Heat meter 2 measure the heat energy produced by the gas boiler that goes to the heating system and to the DHW system. Heat meter 3 measures the heat energy

produced by the solar thermal collectors. The data from meters go to the Mbus master converter, which is connected to a laptop computer. The measured data are recorded with Docom CS software. A more detailed scheme for measuring is presented in Figure 2. The measured data are recorded after every 10 minutes. The heat meters also display the inlet and outlet temperature of the liquid, liquid flow and instantaneous capacity.

According to the measured data it is possible to present the monthly solar thermal energy production (Figure 7). The total annual production from solar collectors is 3586 kWh. Compared to the simulation results the measured production is 8 % lower.

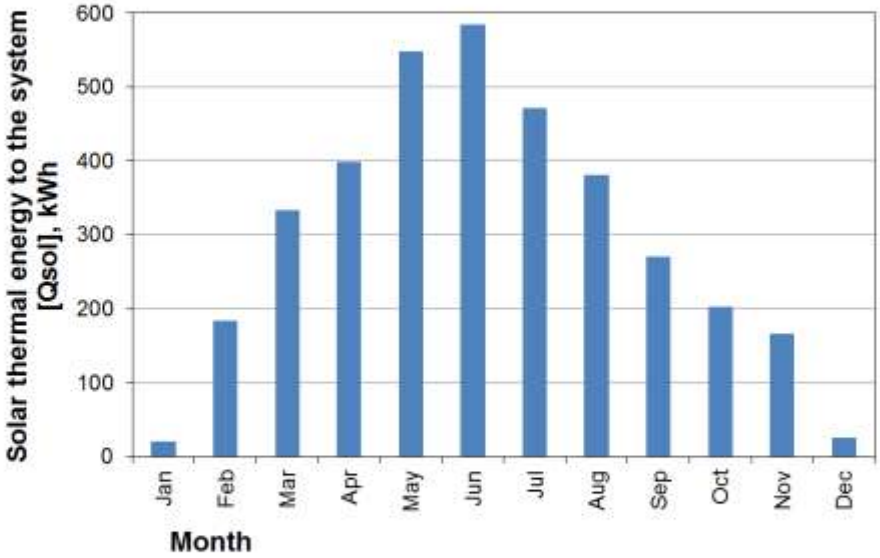

Figure 7 Solar thermal energy to the domestic hot water system in the year 2010 (measured)

To point out the proportion of the heat production of the gas boiler and solar thermal energy, the energy consumption for DHW in the test building is presented in Figure 7. It can be said that in the summer period it is possible to produce a significant part of the DHW with solar thermal collectors. In the winter period the energy production of collectors is significantly lower.

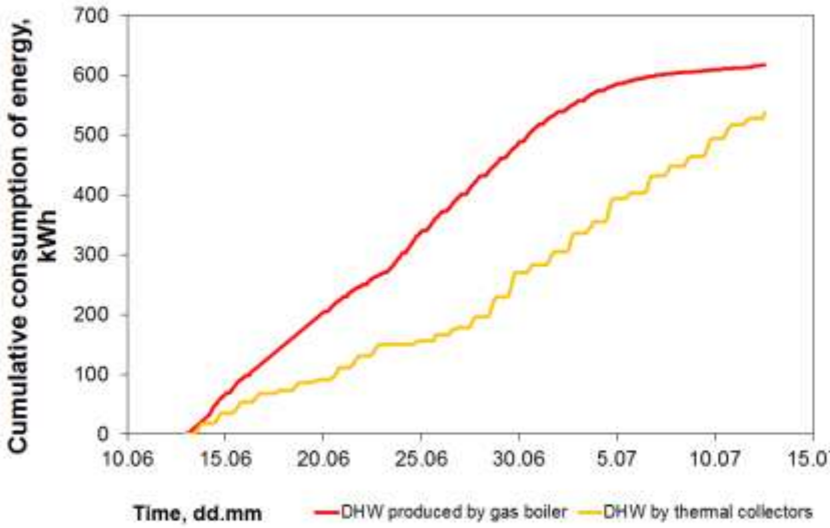

Figure 8 Energy consumption in the test building in the year 2012 (measured)

4. CONCLUSIONS

Approximately over 70% of all Estonian inhabitants live in apartment buildings. Studies show that there is a huge potential for producing DHW by solar thermal systems in apartment buildings. At the same time solar thermal collectors cannot be the only resource for DHW production in North-European countries. The simulation results show that it is possible to produce up to 35% of DHW by solar collectors. The measurements of DHW consumption show that in different buildings it varies widely. If the consumption is higher, the production of collectors is bigger but at the same time the production of solar thermal collectors compared to the total production is lower.

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